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Peru Water Resources: Integrating NASA Earth Observations into Water Resource Planning and Management in Peru's La Libertad Region

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I. Abstract

Developing countries often struggle with providing water security and sanitation services to their populations. An important aspect of improving security and sanitation is developing a comprehensive understanding of the country's water budget. Water For People, a non-profit organization dedicated to providing clean drinking water, is working with the Peruvian government to develop a water budget for the La Libertad region of Peru which includes the creation of an extensive watershed management plan. Currently, the data archive of the necessary variables to create the water management plan is extremely limited. Implementing NASA Earth observations has bolstered the dataset being used by Water For People, and the METRIC (Mapping EvapoTranspiration at High Resolution and Internalized Calibration) model has allowed for the estimation of the evapotranspiration values for the region. Landsat 8 imagery and the DEM (Digital Elevation Model) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor onboard Terra were used to derive the land cover information, and were used in conjunction with local weather data of Cascas from Peru's National Meteorological and Hydrological Service (SENAMHI). Python was used to combine input variables and METRIC model calculations to approximate the evapotranspiration values for the Ochape sub-basin of the Chicama River watershed. Once calculated, the evapotranspiration values and methodology were shared Water For People to help supplement their decision support tools in the La Libertad region of Peru and potentially apply the methodology in other areas of need.

II. Introduction

Background Information:
Many developing countries, like Peru, struggle with providing water security and sanitation services. Water For People, a non-profit dedicated to assisting countries with water sanitation, aims to establish creative, collaborative solutions that allow people to build and maintain their own reliable safe water systems (Water For People, 2014). The organization holds an office in Cascas, the capital of the Gran Chimú province of the La Libertad region of Peru. Water For People's office in Peru strives to help provide water security and sanitation systems to the people of seventeen villages and the 40% of the population within the sub-basin whose systems are deemed unsustainable or in poor condition. Water For People works with the Peruvian government to create the water budget for the La Libertad region, which requires evapotranspiration and precipitation analysis (Water For People, 2014).

Located in the La Libertad region of Peru, the Chicama River serves as the main source of water throughout the region, with the watershed encompassing roughly five thousand square kilometers (ISSUU, 2003, pg. 49). NASA DEVELOP focused on assisting Water For People with the evapotranspiration analysis of the Ochape sub-basin of the Chicama watershed. The Ochape sub-basin, with an area of two-hundred seventeen square kilometers, is located within the La Libertad region and partially within the Cajamarca region as well. The Ochape sub-basin politically covers the provinces of Contumaza and Gran Chimú. The main economic activities of the Ochape sub-basin include livestock and agriculture, exporting crops such as wheat, potatoes, corn, beans, and citruses, though the main agricultural product of the region is beets (ISSUU, 2003, pg. 51). Because of the Ochape's main economic sources, monitoring the water distribution across the sub-basin from the hydrologic cycle is crucial. Evapotranspiration describes the loss of water from the soil by evaporation and also transpiration by plants. Necessary in the creation of the water budget for Peru, Water For People needed the calculated evapotranspiration values across the Ochape sub-basin (Water For People, 2013).

To calculate the evapotranspiration values, the Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) model was developed in collaboration by the University of Idaho and the Idaho Department of Water Resources. METRIC is an image processing model encompassing multiple sub-models for calculating evapotranspiration as a residual of the surface energy balance. Traditionally, evapotranspiration values from agricultural fields were estimated by multiplying the weather based reference evapotranspiration by crop coefficients. However, METRIC allows evapotranspiration values to be calculated without using crop coefficients, but it will often lead to error. As a variant of the Surface Energy Balance Algorithm for Land (SEBAL) model developed by the Netherlands, METRIC's terrain application includes mountainous regions and areas with arid or semi-arid climates, making it applicable for the semi-arid climate and mountainous terrain of the Ochape sub-basin of the Chicama River watershed (Allen, 2007).

There were a multitude of input values that were required to calculate evapotranspiration values. The Operational Land Imager (OLI) sensor from the Landsat 8 satellite was the primary source for the project's input data (Landsat 8 OLI, 2014). The project gathered data from the Landsat 8 satellite for April 2013 through June 2014, and from this it provided thermal bands and land cover data necessary for calculating evapotranspiration. A joint initiative between the U.S. Geological Survey (USGS) and NASA, Landsat provides imagery resources for those working in agriculture, geology, mapping, regional planning, and more (Landsat Project Description, 2013). The other NASA Earth Observing System used for this project was the Advances Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor aboard the Terra satellite. ASTER data has been used to create detailed maps of land surface temperature, reflectance, and elevation since December of 1999 (ASTER, 2004). Elevation data from the ASTER sensor is an important component of measuring the evapotranspiration values through the METRIC model. The final data needed for the inputs in the METRIC model were *in-situ* weather data from a local weather station in Cascas. The data gathered included precipitation (mm, air pressure (mb), humidity (%), wind speed (m/s), and temperature (°C). This information was gathered daily from December 2013 through June 2014, which corresponded to Landsat 8 data availability (Landsat Project Description, 2013). This then became our study period.

The data from the OLI sensor of Landsat 8, ASTER sensor of Terra, and the local weather station at Cascas were fed into a Python script of the METRIC model. Through scripting the METRIC model, the input data could be filtered into the script to output the evapotranspiration values. These values were then displayed in ArcGIS on a map that will be delivered to Water For People for use in creating the watershed management plan and water budget for the La Libertad region of Peru.

The METRIC model for calculating evapotranspiration was chosen to gather the evapotranspiration values for various reasons. As previously mentioned, evapotranspiration from agricultural fields involved multiplying the weather-based reference evapotranspiration by crop coefficients adjusted for crop type and crop growth stage. However, this often leads to error since it is difficult to predict the correct crop growth stage dates for large areas of crops and fields, thus making the METRIC model the most accurate tool for estimating evapotranspiration values (Allen, 2007). METRIC evapotranspiration applications include water planning, water rights monitoring, aquifer depletion, hydrologic modeling, water-use data, and water administration (Allen, 2005). Because of the many applications of METRIC, the METRIC model and the corresponding evapotranspiration calculations are valuable to Water For People in their development of La Libertad's watershed management plan and water budget.

Project Objectives:
The overall goal for this project was to provide the appropriate and relevant data to assist Water For People in their decision-making process. The end-products of the project included the evapotranspiration estimates of the Ochape sub-basin. To get to this end-product, there were several objectives that had to be accomplished throughout the course of this project. First, the appropriate data for our project had to be gathered and formatted so that it could be fed through a Python script. Secondly, the largest project objective encompassed scripting the METRIC model and all fifty-nine corresponding equations into Python. The script had to be tested often to ensure the outputs accuracy. Lastly, the final evapotranspiration values from the Python script were measured and georeferenced so that they could be mapped in ArcGIS.

Study Area:
The specific region for this project is the Ochape sub-basin of the Chicama River watershed, located largely in the Gran Chimú province of the La Libertad region of Peru. The Ochape sub-basin's area is approximately two-hundred seventeen square kilometers, whereas the entire Chicama River watershed covers roughly five thousand square kilometers. The Ochape sub-basin consists of 67 springs, 52 irrigation canals, and 29 reservoirs (Water For People, 2013). There are 34 communities within the sub-basin, and the demographics of the region are 68% rural, and 32% urban (Water For People, 2013). The sub-basin has a warm, dry climate year round and has an average temperature of 18.9°C (Water For People, 2013). The Ochape sub-basin encompasses a mountainous terrain with rolling hills. The maximum altitude reaches four-thousand two-hundred meters (ISSUU- 2003, pg. 53). The main industry of the sub-basin is agriculture with a staple-crop of beets, and the industry of livestock follows.

Study Period:
The study period for the project term is from December 2013 to June 2014, as this is the period of obtainable data from both the Landsat 8 satellite and Cascas weather

station. Landsat 8 is the most recent satellite that gives preliminary evapotranspiration and land cover data, which is the main satellite used for this project (Landsat Project Description, 2013).

National Applications:
The project addressed the "Water Resources" NASA application area and contributed to supporting the goal of broadening NASA Earth observation users and data. Under the Water Resources program, data will be derived and analyzed to assist in water management within the Ochape sub-basin alongside of Water for People (Farmer, 2012).

Project Partners:
The research of this term was completed for and in collaboration with the nonprofit organization, Water for People. Water for People's ultimate goal is to achieve universal clean drinking water and sanitation services for global citizens. They are currently partnered with the regional government of La Libertad within Peru to find solutions to improve water and sanitation services for the region. To do so, they seek to create a comprehensive water management plan that contains a water resource inventory. Before this project, NASA Earth observation data was not being incorporated into this management plan. Because of the limited amount of *in-situ* data within Ochape sub-basin, Water For People wished to incorporate remotely sensed data from NASA EOS into their plan to help bridge the gaps in currently-available data.

III. Methodology

Data Acquisition:
To calculate the evapotranspiration values for the Ochape sub-basin, preliminary data was needed as input variables into the scripted Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) model. Surface temperature, land cover data, thermal bands, and reflectance were retrieved from the OLI sensor of the Landsat 8 satellite. Running since 2013, Landsat 8 served as the most prominent source of information for the evapotranspiration measurements (Landsat Project Description, 2013). Another NASA Earth Observing System used as input data was the ASTER instrument from the Terra satellite, which has been running since December 1999 (ASTER, 2004). ASTER gathered the Digital Elevation Model (DEM) for our sub-basin. This served as an extremely valuable input variable since the elevation for the Ochape sub-basin varies so widely between low lying rivers and mountainous terrain. Lastly, local weather data was collected from the Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI) station in the city of Cascas. This data contained information surrounding precipitation, pressure, humidity, wind speed, and temperature. All of the input variable data was collected monthly starting from December 2013 through June 2014 (Landsat Project Description, 2013). Although the Landsat 8 and Terra satellite data both went as far back as June 2013, weather data through SENAMHI was only accessible from at December 2013, which limited our study period. To acquire the Landsat 8 and Terra satellite data, imagery was downloaded from the USGS EarthExplorer. To collect the weather data, information was retrieved from the SENAMHI

Cascas weather station's online database. Thus, the necessary data for the Ochape sub-basin of the Chicama watershed was acquired and ready to input into the Python script of the METRIC model.

Data Processing:
The data from the OLI sensor of Landsat 8, the ASTER sensor of the Terra satellite, and the local weather station in Cascas was processed by scripting the Mapping Evapotranspiration at High Resolution with Internalized Calibration (METRIC) model. METRIC is an image processing model encompassing multiple sub-models for calculating evapotranspiration as a residual of the surface energy balance equation. Comprised of fifty-nine equations, the METRIC model can be broken down into three main components: net radiation (R_n), sensible heat flux conducted into the ground (G), and sensible heat flux convected into the ground (H). These three sub-categories lead to the calculation of latent energy consumed by evapotranspiration (Allen, 2007).

$$LE = R_n - G - H$$

From the latent energy equation, the METRIC model calculated instantaneous evapotranspiration for the time the satellite image was taken. For this project term, instantaneous evapotranspiration was calculated for December 2013. As seen on the Landsat 8 imagery, this month had limited cloud coverage, which would distort the instantaneous evapotranspiration values if high.

$$ET_{inst} = 3{,}600 \frac{LE}{\lambda \rho_w}$$

The METRIC model can also calculate the average evapotranspiration over a designated period of time, such as a twenty-four hour period (Allen, 2007). However, this project could not calculate twenty-four hour evapotranspiration since Landsat 8 takes images every two months. In order to compute evapotranspiration throughout a day, Landsat 8 images would need to be taken hourly.

$$ET_{24} = C_{rad}(ET_r F)(ET_{r_{24}})$$

To calculate the evapotranspiration values, a Python script was created that automated the METRIC model. The data from Landsat 8, Terra, and the Cascas weather station was used as input variables, allowing the script to run and then output the corresponding instantaneous evapotranspiration values. Although instantaneous evapotranspiration is the final result of the Python script, many intermediate results are output from the METRIC model. For example, soil adjusted vegetation index (SAVI), leaf area index (LAI), and normalized difference vegetation index (NDVI) are all intermediate results of the METRIC model. Although they are considered intermediate results, they are all important aspects of data processing since they are all incorporated into the final calculation of instantaneous evapotranspiration.

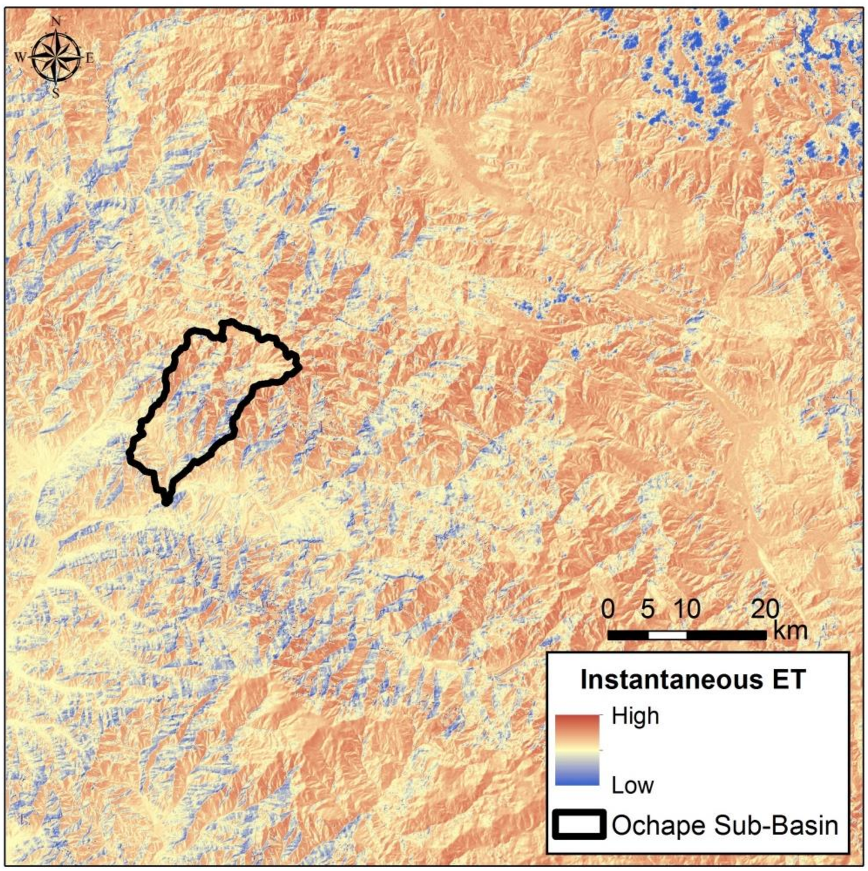
Data Analysis:
Since Python is the primary scripting language for ArcGIS, the instantaneous evapotranspiration calculation output a .tif image with the georeferenced data so that

it could be viewed in ArcGIS. The maps illustrating the instantaneous evapotranspiration values were given to Water For People for assistance in making the watershed management plan, allowing them to easily see which areas of the Ochape sub-basin are holding the most water. These values are essential to Water For People because evapotranspiration is a large aspect of how water is distributed across the region. Areas with high evapotranspiration values also correlate with having low surface temperature, high net radiation, low ground heat flux, and low heat flux to air. Vegetation, water availability, and evapotranspiration are also all interrelated. Because evapotranspiration holds many different relationships concerning water maintenance, this provides a large database of information for Water For People to reference when creating the watershed management plan and water budget for La Libertad, Peru (Morse, 2006).

IV. Results & Discussion

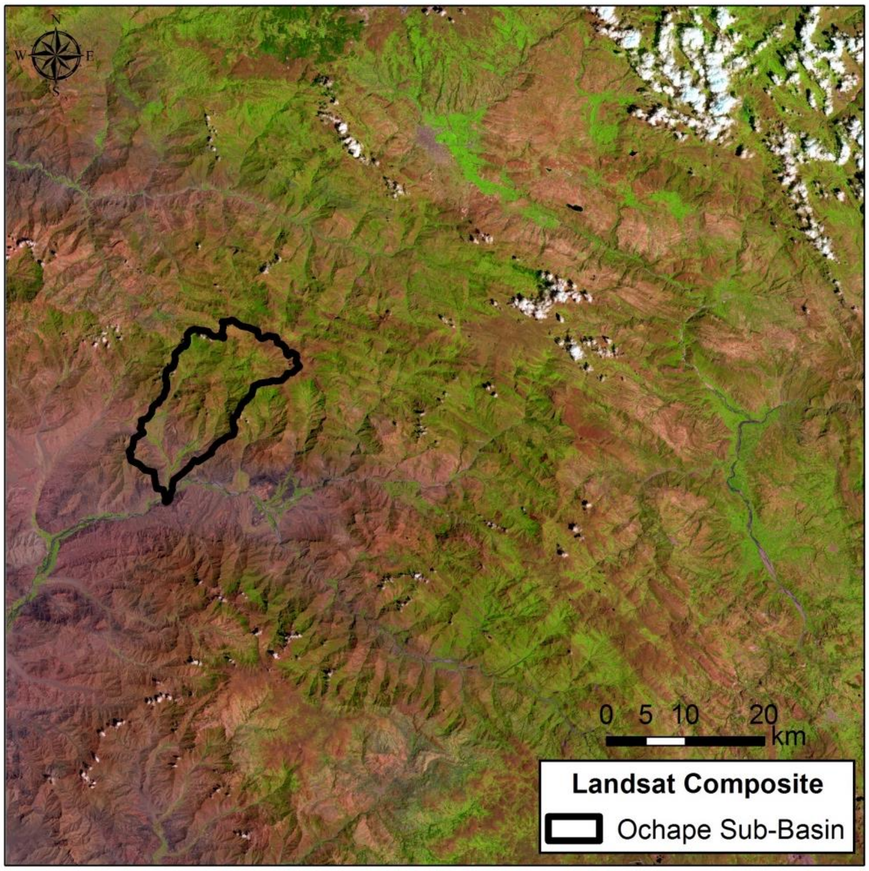
Analysis of Results:

Instantaneous Evapotranspiration for the Ochape Sub-Basin

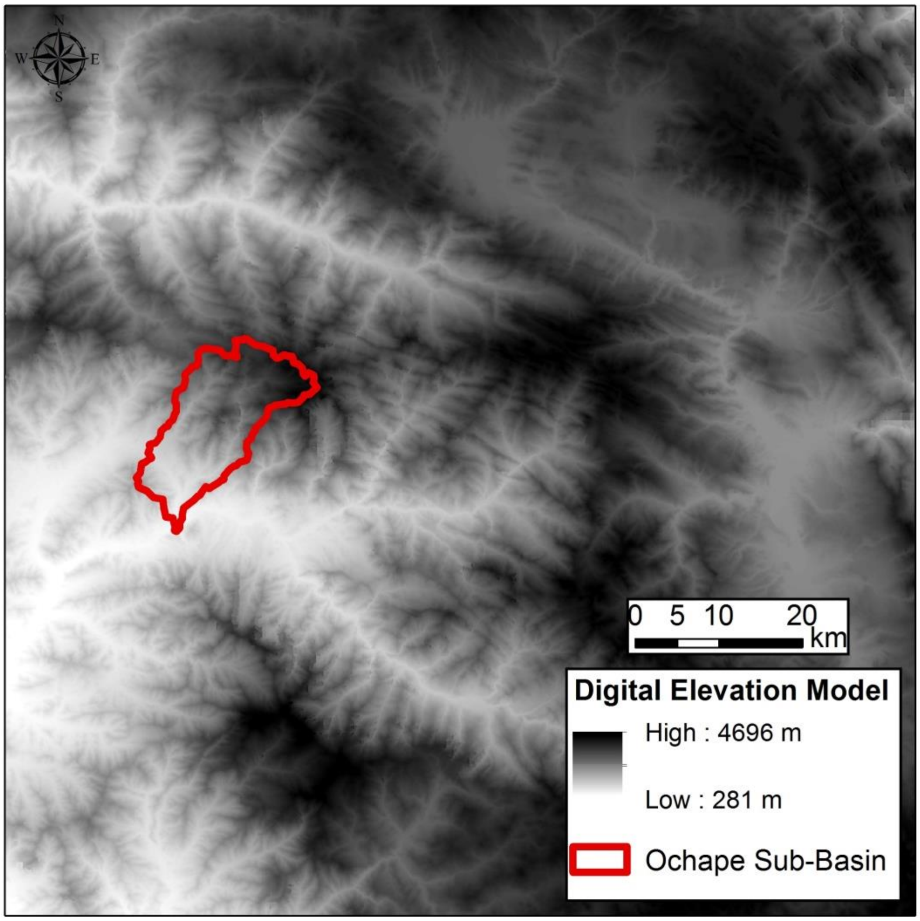


Evapotranspiration is a significant component of the hydrologic cycle because it represents a considerable amount of moisture lost from a watershed (Allen, 2005). When analyzing the evapotranspiration map above, Water For People can see the areas of the sub-basin that are losing the highest amount of water. Some correlations can also be inferred from this visualization in comparison to the Landsat 8 true color imagery and the digital elevation model below. When observing the Landsat 8 true color imagery, the areas that are greener have higher instantaneous evapotranspiration values. When analyzing the digital elevation model against the evapotranspiration map, there appears to be direct relationship between elevation and evapotranspiration. The higher the elevation, the higher the instantaneous evapotranspiration is for that area.

Landsat 8 True Color Image



Digital Elevation Model



Errors and Uncertainty:
There are a multiple errors that arise from using the METRIC model to calculate evapotranspiration. One of the main errors in this project stems from the lack of daily satellite imagery. Landsat 8 takes imagery one every two weeks, which was enough to calculate instantaneous evapotranspiration. However, daily values of evapotranspiration are generally more useful and accurate than instantaneous evapotranspiration (Allen, 2007). While the METRIC model is considered a "hands-off" technique for calculation evapotranspiration, the model does specify that only highly trained experts surrounding vegetation and radiation physics should execute the METRIC model. Also, since the METRIC model was originally developed for Idaho and its corresponding climate and terrain, there may be some errors in the application of METRIC to the La Libertad region of Peru.

Future Work:
The Python script developed of the METRIC model used by another NASA DEVELOP team this term, which completed a different water resources project concerning the calculation of evapotranspiration for the Coastal Mid-Atlantic region. The METRIC model was also handed to Water For People so that evapotranspiration can be

calculated for different regions not only across Peru but also across the different continents. If this project was picked for a second term, the METRIC model could be applied to more months of the Ochape sub-bain, allowing evapotranspiration to be analyzed throughout a period of time. The METRIC model could also be strengthened and extended to encompass the calculation of twenty-four hour evapotranspiration. However, this would not be useful unless a satellite similar to Landsat 8 existed that took images of a region hourly.

V. Conclusions

Throughout the course of this project, several conclusions could be made surrounding evapotranspiration and its significance. Evapotranspiration from individual fields can assist in water planning, water rights monitoring, water-use data, and water administration. Evapotranspiration, vegetation, and water availability are also interrelated (Allen, 2005). Also, the scripted METRIC model allows for the calculation of evapotranspiration for different regions by both Water For People and future NASA DEVELOP projects.

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VIII. Appendices

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14. ABSTRACT

Developing countries often struggle with providing water security and sanitation services to their populations. An important aspect of improving security and sanitation is developing a comprehensive understanding of the country's water budget. Water For People, a non-profit organization dedicated to providing clean drinking water, is working with the Peruvian government to develop a water budget for the La Libertad region of Peru which includes the creation of an extensive watershed management plan. Landsat 8 imagery and ASTER DEM were used to derive the land cover information, and were used in conjunction with local weather data of Cascas from Peru's National Meteorological and Hydrological Service (SENAMHI).

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